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Chapter 5. Managing an Uncertain Future

About This Chapter

Chapter 5, Managing an Uncertain Future, emphasizes the need for decision-makers, water and resource managers, and land use planners to use a range of considerations in planning for California's water future in the face of many uncertainties and risks. It provides examples of uncertainties and discusses the need to assess risks in planning for actions with more sustainable outcomes. A framework is provided to measure the sustainability of water management policies and projects. An approach is presented for evaluating resource management strategies for robustness using multiple future scenarios. Water management vulnerabilities identified during preparation of this Water Plan update are presented.

- Planning Approach
- Recognizing and Reducing Uncertainty
- Assessing Risk
- Managing for Sustainability
- Planning for an Uncertain Future
- Summary

Planning Approach

Overview

The Water Plan includes a framework for improving water reliability through two initiatives. One initiative places emphasis on integrated regional water management to make better use of local water sources by integrating multiple aspects of managing water and related resources such as water quality, local and imported water supplies, watershed protection, wastewater treatment and water recycling, and protection of local ecosystems. The second initiative places emphasis on maintaining and improving statewide water management systems. These two initiatives are at the root of the strategic plan in Update 2013 to secure reliable and clean water supplies through 2050. The Water Plan acknowledges that planning for the future is uncertain and that change will continue to occur (see Box 5-1). Update 2013 builds on three key considerations in the planning approach for future management of regional and statewide water resources. The planning approach should (1) recognize and reduce uncertainties inherent in the system, (2) define and assess the risks that can hamper successful system management and select management practices that reduce the risks to acceptable levels, and (3) keep an eye toward approaches that help implement and maintain water and flood management systems that have more sustainable outcomes.

PLACEHOLDER Box 5-1 Uncertainty, Risk, and Sustainability

[Any draft tables, figures, and boxes that accompany this text for the advisory committee draft are included at the end of the chapter.]

PLACEHOLDER Box 5-2 Abbreviations and Acronyms Used in this Chapter

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Traditional Planning Approach—The Past is a Model for the Future

Water managers have always recognized the variable waterflow in California's streams and rivers during wet and dry periods spanning from seasons to multiple years. Having too little water or too much water—droughts or floods—were often the main reasons that Californians built early water projects. Early in California's water development history, personal observations, and experience were often used to help size water facilities because of the limited availability of recorded data.

A system to record waterflow conditions over time gradually improved information available to water managers. However, the main assumption governing water management for much of California's history has been that past records were a good indication of the frequency, duration, and severity of future floods and droughts, and these were used as models of potential future conditions. In addition, historical records were generally used to establish trends, such as population growth, that were assumed to continue into the future.

This static view of the range of possible future conditions worked fairly well when the demands on the resources were considerably lower than now. Early designers may have understood the variability of storm events and the range of streamflows that could occur and the likelihood that a reservoir would refill in a given year, but generally they did not fully understand the interrelationships among ecosystem issues, flood management issues, water availability issues, water use issues, and water quality issues.

The early approach to flood planning focused on flood damage reduction and public safety. These projects were designed to control and capture flood flows using measures such as dams, levee systems, bypasses, and channel enlargements. Although these projects provided significant flood protection benefits, some of these early structural projects caused unintended consequences of larger peak flows, conflicts with environmental resources, and increased flood risks. These experiences have prompted flood planners to look more comprehensively at flood systems to gain a better understanding of floodplains, related water supply, and environmental systems to provide multiple benefits.

In addition, risks posed by earthquakes, extreme floods, and extreme droughts were generally underestimated. Without a complete acknowledgement of the uncertainties inherent in the system and the risks that the system actually faced, the system management was relatively simple compared with today's standards. Conditions appeared more certain and less risky than they actually were, and water managers were more focused on meeting shorter term objectives. Although understanding the past is still an important part of managing for the future, it is becoming increasingly apparent that continued management under this traditional approach will not provide for sustainable water resources into the future.

New Planning Approach—Anticipate Change

Today, as part of integrated regional water management and integrated flood management, California's water and resource managers must recognize that conditions are changing and that they will continue to change. Traditional approaches for predicting the future based solely on projecting past trends will no longer work. Today, there is better understanding that strategies for future water management must be dynamic, adaptive, and durable. In addition, the strategies must be comprehensive and integrate physical, biological, and social sciences.

California's water management system is large and complex with decentralized water governance that requires a great deal of cooperation and collaboration among decision-makers at the State, federal, tribal, regional, and local level. California lacks a common analytical framework and approach for these entities to understand and manage the system, especially when management actions may compete for the same resources. The entities must make sound investments that balance risk with reward, given today's uncertainties and those that may occur in the future. The Water Plan emphasizes the benefits of integrated water management when considering strategic investments.

As described in more detail in Chapter 6, the California Water Plan promotes ways to develop a common approach for data standards and for understanding, evaluating, and improving regional and statewide water management systems, and for common ways to evaluate and select from alternative management strategies and projects. The Department of Water Resources (DWR) has initiated work on the Water Planning Information Exchange (Water PIE). This system for accessing and sharing data across existing networked databases would use web services and GIS software to improve analytical capabilities and develop timely surveys of statewide land use, water use, and estimates of future implementation of resource management strategies. Water PIE will build on and complement several existing data sharing sites managed by DWR including the Water Data Library, California Data Exchange Center, and the California Irrigation Management Information System.

The California Water Plan acknowledges that planning for the future is uncertain and that change will continue to occur. It is not possible to know for certain how population growth, land use decisions, water demand patterns, environmental conditions, the climate, and many other factors that affect water use and supply may change by 2050. To anticipate change, our approach to water management and planning for the future needs to consider and quantify uncertainty, risk, and sustainability.

- **Uncertainty.** There are enormous uncertainties facing water managers in planning for the future. How water demands will change in the future, how ecosystem health will respond to human use of water resources, what disasters may disrupt the water system, and how climate change may affect water availability, water use, water quality, and the ecosystem are just a few uncertainties that must be considered. The goal is to anticipate and reduce future uncertainties, and to develop water management strategies that will perform well despite uncertainty about the future. Uncertainties will never be eliminated, but better data collection and management and improved analytical tools will allow water and resource managers to better understand risks within the system. Many water agencies in California have begun incorporating climate change information into their operation and planning process in order to reduce uncertainty of how climate may impact California's water resources in the future. Additional efforts are needed to develop the accurate climate data needed to reduce uncertainty and risk in California water management in the future. To read more about the development of DWR's Climate Science program see the Volume 4 article, "The State of Climate Change Science for Water Resources Operation, Planning, and Management", and visit http://www.water.ca.gov/climatechange.
- **Risks.** Uncertainties about future conditions result in water-related risks. Each undesirable event has a certain, but unknown, chance of occurring and a set of consequences should it

occur. Combining the likelihoods with consequences yields estimates of risk. For example, a chance of a levee failure with a certain sized flood event can be estimated with associated economic and human consequences. Likewise, one can estimate the likelihood of a drought of a specific severity and combine this with estimates of the consequences.

- By reducing the uncertainties described above, the "true" risks can be reduced. State government and other entities are performing risk assessments that can be used in future planning to balance risk with reward when implementing new management actions. Risk assessments are also a way to quantitatively consider the uncertainties that relate to events of interest such as the performance of levees, the consequences of flooding, and the impact of events on the environment. More information on these risk assessments can be found later in this chapter.
- **Sustainability.** Given the uncertainties and risks in the water system, some management strategies may provide for more sustainable water supply and flood management systems, and ecosystems than another set of management strategies. Recognizing that change will continue to occur and that additional uncertainties and risks are likely to surface in the future, water management must be dynamic, adaptive, and durable. As described later in this chapter, DWR has developed a draft framework for quantifying indicators of water sustainability and has begun testing the indicators in regional pilot studies.

We have no way no of predicting the future, but we can construct scenarios. Future scenarios can be used to help us better understand the implications of future conditions on water management. This Water Plan considers several alternative, plausible, yet very different future scenarios as a way to consider uncertainty and risk and to improve resource sustainability. One scenario is a projection of current trends. Another scenario considers lower population growth and other factors that may require less intensive use of resources. A third scenario covers the possibility of more expansive population growth and other factors that would result in more intensive use of resources. The concept is not to plan for any one given future as in past water plan updates, but to look at how each future scenario could be managed. Certain combinations of management strategies, or response packages, may prove to be robust regardless of the future conditions. This is especially true if the response packages have a degree of adaptability to differing conditions that may develop. A general description of the scenarios can be found later in this chapter.

Recognizing and Reducing Uncertainty

There are two broad types of uncertainty:

- The first type of uncertainty is from the inherent randomness of events in nature such as the occurrence of an earthquake or a flood. This type of uncertainty is known as *aleatory* uncertainty and cannot be reduced by collection of additional data. However, additional data may allow better quantification of uncertainty.
- The second type of uncertainty can be attributed to lack of knowledge or scientific understanding. This type of uncertainty is known as *epistemic* (knowledge-based) uncertainty. In principle, epistemic uncertainty can be reduced with improved knowledge that comes from collection of additional information.

Although it is not necessary to categorize uncertainty for the Water Plan update into these two types of uncertainty, it is important consider these while improving data collection and analytical tools.

California's water and resource managers must deal with a broad range of uncertainty. Uncertainty is inherent in the existing system and in all changes that may occur in the future. For example, although water managers can be certain that the flows in California's rivers will be different next year compared with this year, they do not know the exact magnitude or timing of those changes. The threat of a chemical spill that may disrupt water diversion presents uncertainty. Future protections for endangered species may require modifications in water operation procedures that are unknown today. Scientists are trying to understand the reasons for the pelagic fish decline in the Sacramento-San Joaquin River Delta (the Delta), the condition of levees throughout the state, and the extent of groundwater recharge and overdraft to name a few.

For the purposes of considering potential future changes and their inherent uncertainties, it is useful to consider and measure how change may occur: gradual changes over the long-term or more rapid or sudden changes over the short-term. Gradual changes can include things like variation in population by region, shifts in the types and amount of crops grown in an area, or changes in precipitation patterns or sea level rise. Sudden changes can include episodic events such as earthquakes, floods, droughts, equipment failures, chemical spills, or intentional acts of destruction. The nature of these changes, the uncertainties about their occurrence, and their potential impacts on water management systems can greatly influence how to respond to the changes. Box 5-3 shows some sources of future change and uncertainty.

PLACEHOLDER Box 5-3 Sources of Future Change and Uncertainty

[Any draft tables, figures, and boxes that accompany this text for the advisory committee draft are included at the end of the chapter.]

Assessing Risk

With improved understanding of uncertainties, risks facing future operation of the system can be better assessed. Most risks originate from hazards like floods, earthquakes, and droughts. But risks can also be due to other issues like water demands growing faster than anticipated, salt water intrusion, or land subsidence caused by groundwater overdraft. Risk can be defined as the probability that some undesirable event will occur, which is usually linked with a description of the corresponding consequences of that event, or:

Risk = the probability of the occurrence (times) the consequences of the occurrence

For example, the risk for a flooding hazard is determined as follows:

- Probability equals the frequency of the storm event that causes a levee to fail, say 1 percent chance each year.
- Consequences equal the effects of the floodwater from the levee failure upon the human and natural environment; say $100 million in damages.
- The expected annual risk for an event with a 1% chance of occurring each year would be 0.01 X $100 million, or $1 million per year.

Figure 5-1 further demonstrates risk for flooding from a levee failure.

PLACEHOLDER Figure 5-1 Understanding Flood Risks

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Accounting for Risk

Although it is impossible to account for all uncertainties and risks in a planning study, techniques can be used to acknowledge their existence and to assign some quantitative importance to them in the analysis. These techniques include direct enumeration, sensitivity analysis, scenario analysis, probability analysis, game theory, robust decision methods, and stochastic simulation. Planners may combine analyses, such as performing scenario analysis supported by probability analysis.

- **Direct enumeration.** With this technique, all possible outcomes are listed. Although this would provide decision-makers an idea of the possible outcomes of an action, it does not provide any clue to the probability of one event happening over another. Also, given the complex relationships that are involved in most water resource-related studies, all possible outcomes are not likely to be known.
- **Sensitivity analysis.** In sensitivity analysis, the values of important factors can be varied to test their effects upon the system being analyzed. These factors can be tested one at a time to find ones that have a significant impact on the results and those that do not. An example of this would be to vary the assumption about future energy costs. If different energy costs do not have a significant effect upon the relative ranking of the proposed project relative to its alternatives, the analyst may feel more comfortable with the project. Although sensitivity analysis is relatively easy to do, it has drawbacks: (a) it frequently assumes that the appropriate range of values is known and that all values are equally likely to occur and (b) the results of the analysis are often reported as a single, most likely value that is considered precise.
- **Scenario analysis.** Scenario analysis is similar to sensitivity analysis except groups of factors are tested to together in a methodical way. Each scenario includes factors that support a given theme or story. For example, one scenario could include factors that imply high growth in demand for water and another could include factors that support low growth in demand for water. In this way, scenarios can be compared. This Water Plan uses scenario analysis to consider possible future conditions.
- **Probability analysis.** Although it is recognized that the “true” values of planning and design variables and parameters are not known with certainty and can take on a range of values, it may be possible to describe a variable or parameter in terms of a probability distribution. For example, for a normally distributed variable or parameter, indicators such as mean and variance can be identified which would allow confidence intervals to be placed around point estimates. In other words, instead of saying the benefit/cost (B/C) ratio for a project is 1.20, we might be able to say that we are 90 percent confident that the B/C ratio exceeds the value of 1.15, which gives the decision-makers more information to consider.
- **Robust decision methods.** Robust decision methods are designed to help decision-makers identify solutions (or resource management strategies) that are robust across a wide range of plausible future conditions. These methods are particularly useful when uncertainties cannot easily be characterized using probability distributions. Many argue, for example, that we do not

know enough about how the climate may change in response to greenhouse gas emissions and other natural changes, to assign meaningful probabilities to individual climate scenarios. Robust Decision-making (RDM) is a specific robust decision method that systematically identifies the key vulnerabilities of promising water management strategies and then guides the development of more robust options.

Researchers with RAND Corporation and Penn State University are evaluating how RDM methods can used in conjunction with methods to optimize systems with multiple, complex objectives. This method, referred to as Many Objective Robust Decision Making, is described in Box 5-4.

- **Stochastic simulation**. This is also known as Monte Carlo simulation or model sampling. An example of this type of analysis is the US Army Corps of Engineers' (USACE) software program, HEC-FDA (Flood Damage Assessment) that directly incorporates uncertainties into a flood damage analysis. For example, direct inputs into this program include frequency/discharge, stage/discharge, and structural inventories for which stage/damage curves are determined within the program. FDA statistically assigns error bands around all of these relationships, and then through a Monte Carlo analysis, samples within the various relationships' error bands in order to determine expected annual damage. Although this program is still subject to the same fundamental sources of uncertainty (model specification and data collection/measurement), at least it explicitly attempts to incorporate uncertainty into the flood damage analysis.

PLACEHOLDER Box 5-4 Many Objective Robust Decision Making

[Any draft tables, figures, and boxes that accompany this text for the advisory committee draft are included at the end of the chapter.]

Risk Assessment Examples

As mentioned, risk assessments provide a way to quantitatively consider the uncertainties that relate to events of interest. DWR and others are beginning to conduct more risk assessments as part of planning for the future. The Water Plan encourages all resource planners to incorporate risk assessments into their planning for integrated regional water management, which includes integrated flood management. This provides the basis for balancing risks with rewards in planning for more sustainable outcomes. Some examples of ongoing risk assessments are given here.

Central Valley Flood Protection Plan*.* On June 29, 2012 the Central Valley Flood Protection Board unanimously adopted the Central Valley Flood Protection Plan (CVFPP), a comprehensive new framework for systemwide flood management and flood risk reduction in the Sacramento and San Joaquin River Basins (CA DWR 2012). The CVFPP provides conceptual guidance to reduce the risk of flooding for about one million people and $70 billion in infrastructure, homes and businesses with the goal of providing 200-year (1 chance in 200 of flooding in any year) protection to urban areas and reducing flood risks to small communities and rural agricultural lands. The CVFPP proposes a systemwide investment approach for sustainable, integrated flood management in areas currently protected by facilities of the State Plan of Flood Control. The CVFPP will be updated every five years, with each update providing support for subsequent policy, program, and project implementation.

California's Flood Future: Recommendations for Managing California's Flood Risk. DWR and the U.S. Army Corps of Engineers are conducting the first characterization of statewide flood risk, along with the challenges, opportunities, and recommendations for improving and financing flood management as part of integrated water management activities. The California Flood Future Report (See http://www.water.ca.gov/sfmp/ for additional information about the California Flood Future Report). will also explore financing, institutional, legislative and policy options available to help improve local and regional flood management systems. A public review draft of the Flood Future Report will be issued in 2012, and a final version will be issued in 2014.

Delta Risk Management Strategy. The Delta Risk Management Strategy (DRMS) completed a study evaluating Delta issues from the perspective of the risks from levee failures and ways to reduce those risks (URS 2011). DRMS provides a framework for evaluating major threats to the Delta levee system and the impacts that levee failure can have on the Delta ecosystem and economy, the State's water delivery system and other infrastructure, and those who rely on the exports of fresh water from the Delta.

The DRMS assessment provides preliminary estimates of the probability that multiple islands will flood simultaneously during a 25-year exposure period due to a seismic event as shown in Figure 5-2. For example, there is a 40 percent probability of a major earthquake causing 27 or more islands to flood at the same time in the 25-year period from 2005 to 2030. DRMS estimated that if 20 islands were flooded as a result of a major earthquake, the export of fresh water from the Delta could be interrupted for about a year and a half. Water supply losses of up to 8 million acre-feet would be incurred by State and federal water contractors and local water districts.

For more information on DRMS, visit the website at www.drms.water.ca.gov/.

PLACEHOLDER Figure 5-2 Probability of a Number of Simultaneous Levee Failures from a Seismic Event during a 25-year Exposure Period

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California Statewide Levee Database. California has more than 13,000 miles of levees that protect residential and agricultural lands. The levee failures in New Orleans during hurricane Katrina prompted DWR to initiate development of a state-of-the-art levee database for the purpose of better understanding and managing levees. The California Levee Database (CLD) will support an efficient and effective approach for assessing levee reliability, risk assessment factors, and structural data impacting individual levee reaches. Currently, the California Levee Database has location information for more than 10,000 miles of levees and flood control structures throughout California. The CLD is being coordinated with a similar nationwide database being developed by the USACE.

DWR Economic Analysis for Flood Risk Management. DWR has prepared its Economic Analysis Guidebook (DWR 2008 www.water.ca.gov/economics/guidance.cfm) to set forth procedures for consistent economic analysis by DWR for the large list of flood risk reduction studies and projects that are under way or will be started over the next several years. These include major analyses for the Central Valley Flood Protection Plan, the State Plan of Flood Control, regional flood management planning, and various grant programs.

DWR has a policy that, with the exception of the economic discount rate used, economic analyses conducted for its internal use on programs and projects be consistent with the National Economic Development and Regional Economic Development analysis approaches used in the federal Economics and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies (P&G). The P&G procedures are technically sound and using them facilitates coordination with the considerable water management partnerships DWR has with the federal government. Adopted by the US Water Resources Council on March 10, 1983, the P&G is currently being revised. In addition, The USACE requires that risk analysis be conducted for all of its flood damage reduction studies. For agencies seeking USACE funding and/or levee certification, approved risk analyses must be applied. USACE guidance on risk analysis can be found in:

- EM 1110-2-1619, Risk-Based Analysis for Flood Damage Reduction Studies, August 1996 and
- ER 1105-2-101, Risk Analysis for Flood Damage Reduction Studies, January 2006

Least-Cost Planning Simulation Model. DWR developed the Least-Cost Planning Simulation Model (LCPSIM) to evaluate risks of water supply shortages. It is a yearly time-step simulation/optimization model that assesses the economic benefits and costs of enhancing urban water service reliability at a regional level (www.water.ca.gov/economics/models.cfm). The LCPSIM output includes the economically efficient level of adoption of reliability enhancement measures by type, including the cost of those measures. The LCPSIM accounts for the ability of shortage event management (contingency) measures, including water transfers, to mitigate regional costs and losses associated with shortage events as well as the ability of long-run demand reduction and supply augmentation measures to reduce the frequency, magnitude, and duration of those shortage events. Forgone use is the difference between the quantity of water demanded and the supply available for use.

Presenting Uncertainty About Climate Change to Water-Resource Managers. This report documents a series of three workshops conducted by RAND with the Inland Empire Utilities Agency (IEUA) in Southern California in fall 2006 (RAND 2008). The workshops were supported by modeling to explore how different descriptions of uncertainty about the effects of climate change and other key factors on IEUA's projected supply and demand might influence water managers' perceptions of risk and preferences for new infrastructure investments, changes in operational policies, and adoption of regulatory measures. RAND used RDM analysis to decision support when conditions present deep uncertainty. RDM uses computational methods to identify scenarios likeliest to break assumptions embedded in a long-term resource-management plan.

The report presents a decision analysis of potential IEUA-region water-planning responses using three different formulations of uncertainty: traditional scenarios; long-term, probabilistic forecasts; and policy-relevant scenarios. The modeling showed periods of water shortages under different scenarios. As one example, Figure 5-3 shows estimated supply conditions for one scenario.

PLACEHOLDER Figure 5-3 Delivered Supply, Surplus, and Shortages for the Hotter and Drier Miss Goals Scenario under the 2005 IEUA Urban Water Management Plan

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Managing for Sustainability

With a growing recognition that California's water systems are finite, and faced with climate change, growing population, and more stringent environmental requirements, decision-makers, water managers, and planners are becoming increasingly aware of the need to both sustainably manage water and respond to changing availability and constraints on water. In the Water Plan Updates 2005 and 2009, the State refocused attention on the sustainability of California's water systems and ecosystems in light of current water management practices and expected future changes. However, one recurring question from stakeholders has been,

> "How can we ascertain that the objectives of the Water Plan, associated resource management strategies, and recommended actions would lead to sustainable water use and supply for the State and its ten hydrologic regions?"

To respond to the above concern, one of the guiding principles established for decision-making in the California Water Plan Update 2009 was:

> "Determine values for economic, environmental, and social benefits, costs, and tradeoffs to base investment decisions on sustainability indicators."

However, there are major impediments to address the state's water sustainability using sustainability indicators. These include inconsistent terminologies and definitions used; absence of a systematic analytic framework and methodologies for quantification of water sustainability indicators; and a potential lack of data to undertake the appropriate analysis to assess sustainability of water resources through the development and on-going tracking of a set of sustainability indicators.

As part of the Water Plan Update 2013, the Department has developed an analytical and quantitative framework, and a set of preliminary sustainability indicators. The developed framework is intended to help us identify, compute, and evaluate a set of relevant sustainability indicators that would help monitor progress towards sustainability of natural and human water systems.

What is Sustainability?

The word "sustainability" has been widely used in recent years for a wide variety of planning activities, and often no definition is provided with its use. The need for "sustainable development" or "sustainable use of resources" may have somewhat different meanings depending on the perspective of the user. A system or process that is sustainable can generally continue indefinitely. A system that is sustainable, should meet today's needs without compromising the ability of future generations to meet their own needs. A sustainable system generally provides for the economy, the ecosystem, and social equity. Box 5-5 shows a few of the particular relevant sustainability definitions.

The California Water Plan includes a vision statement laying the foundation for how California can be sustainable in water use and management. The vision is the following:

> California has healthy watersheds and integrated, reliable, and secure water resources and management systems that: Enhance public health, safety, and

> quality of life in all its communities; Sustain economic growth, business vitality, and agricultural productivity; and Protect and restore California's unique biological diversity, ecological values, and cultural heritage

PLACEHOLDER Box 5-5 Sustainability Definitions

[Any draft tables, figures, and boxes that accompany this text for the advisory committee draft are included at the end of the chapter.]

In order to help meet the vision of the Water Plan, the following definition for sustainability has been adopted:

> Water sustainability is the dynamic state of water use and supply that meets today's needs without compromising the long-term capacity of the natural and human aspects of the water system to meet the needs of future generations

Water Sustainability Indicators

Indicators are qualitative or quantitative parameters from monitoring programs (e.g., streamflow) selected to represent parts of ecological, social, or economic systems. Definitions of various terms that are related to indicators are provided in Table 5-1. Indicators provide a way to collect information about a condition and to report and compare condition over time. Sustainability indicators measure the condition of parts of the systems, and/or performance of our actions, as well as our distance from and progress toward a range of sustainability. The California Water Sustainability Indicators Framework (Framework) has been developed to assess and monitor progress towards water sustainability through a set of relevant indicators.

PLACEHOLDER Table 5-1 Definitions of Terms Related to Indicators

[Any draft tables, figures, and boxes that accompany this text for the advisory committee draft are included at the end of the chapter.]

The Framework uses the structure of a vision-goals-objectives-indicators nested hierarchy (Figure 5-4). It is organized into a series of steps and each step builds on the previous one. Completing each step leads to subsequent steps and all steps are necessary for a full evaluation of water sustainability. A sequence of steps begins with developing vision, goals, and objectives (going from left to right), identifying indicators for each objective, evaluating indicator condition relative to reference conditions, and reporting indicator conditions to inform knowledge development and policy decisions. Important terms used in the Framework are defined in Table 5-2. Thus indicators can be used to assess and monitor achievement of objectives and progress toward goals.

PLACEHOLDER Figure 5-4 The California Water Sustainability Indicators Framework

[Any draft tables, figures, and boxes that accompany this text for the advisory committee draft are included at the end of the chapter.]

PLACEHOLDER Table 5-2 Definitions of Terms Used in the California Water Sustainability Indicators Framework

[Any draft tables, figures, and boxes that accompany this text for the advisory committee draft are included at the end of the chapter.]

The foundation of the Framework is a set of sustainability goals and associated objectives. The water sustainability goals and objectives included in the Framework derive their meaning and much of their text from the Water Plan statements of intent, but attempt to make clearer connections with the idea of sustainability across ecosystem, social system, and economic system. The Water Plan Objectives are also referred to, in order to ensure consistency with the several ways that the Water Plan describes sustainable management of water. Thus the Framework can be used to evaluate whether meeting the goals, objectives, and resource management strategies of the Water Plan leads towards sustainable water use and supply in California. The eight sustainability goals of the Framework and the associated objectives are furnished in Table 5-3.

PLACEHOLDER Table 5-3 Sustainability Goals and Objectives for California Water

[Any draft tables, figures, and boxes that accompany this text for the advisory committee draft are included at the end of the chapter.]

Indicators provide the connection between statements of intent (e.g., objectives) and measurable aspects of natural and human systems. Because of the importance of the indicators in determining findings and basing decisions, the indicators should be carefully chosen. Explicit criteria must be used to select indicators to ensure that the resulting evaluation is robust and usable in decision-making. Candidate indicators from an extensive review of global systems and from programs in California were evaluated relative to the indicator selection criteria and are listed in Volume 4, Reference guide, California Water Sustainability Indicators Framework, Appendix D. This exercise resulted in a set of indicators that efficiently covered the sustainability objectives, while covering various sectors of concern (e.g., water quality).

For a detailed description of the Framework, see Volume 4, Reference guide, California Water Sustainability Indicators Framework

Water Footprint as an Index of Sustainability

The Framework includes the water footprint as an important index of human impacts to water systems. It is not intended to not replace other indicators, but to serve as an additional, composite index of multiple indicators of human uses of water and impact on natural systems. The water footprint is the relationship between direct or indirect uses of water used to produce goods and services consumed by humanity. Agricultural production accounts for most of water use, but drinking, manufacturing, cooking, recreation, washing, cleaning, landscaping, cooling, and processing all contribute to water use. In addition to these direct water uses, indirect uses such as water impacted by pollutants, chemical or temperature, contribute to the water footprint (see Volume 4, Reference guide, California Water Sustainability Indicators Framework, Appendix H). The water footprint will be used as an index, composed of multiple indicators of water use, along with the other selected indicators of system condition.

The Water Footprint comprises three functions of water labeled by color: green water, blue water, and grey water. The definitions related to water footprint are provided in Table5-4.

PLACEHOLDER Table 5-4 Water Footprint and Related Terms

[Any draft tables, figures, and boxes that accompany this text for the advisory committee draft are included at the end of the chapter.]

The Water Footprint is expected, with improved spatial tracking, to illuminate the material flow of resources. Location-specific data on water use by crop type provides a further level of regional specificity. Based on the best available data, the footprint of production can be compared to the footprint of consumption to determine water sustainability at the statewide scale. Contingent upon data availability, the water footprint analyses could be extended at the regional scales. The water footprint provides a connection between the more traditional world of condition indicators and a comprehensive way of measuring and describing our effects on natural systems as it relates to the use of water.

Statewide and Regional Pilot Studies, and Regional Planning

[Results of this section are under development and will be included in the Public Review Draft. To demonstrate the utility of the Framework, two quantitative pilot studies will be conducted – one at the hydrologic region/state level and the other at the regional level. The main purpose of the pilot studies is to test the Framework with real data. The Pilot studies at both spatial scales will include sustainability indicators and water footprint.]

Water Sustainability Decision Support Tool

[Results under development and will be included in the Public Review Draft. The water sustainability decision support tool (DST) is being developed for visualizing data from the water footprint and water sustainability indicators]

Examples of Managing for Sustainability

A number of concurrent efforts are underway at the regional, State, and federal levels that have as their goals managing natural resources more sustainably. Brief descriptions of these efforts are furnished below.

Strategic Growth Council (SGC): The SGC is a cabinet level committee established in 2008 by Senate Bill 732 that is tasked with coordinating the activities of member state agencies to support sustainable land, air, and water conditions and community well-being (http://sgc.ca.gov/). The 2010 California Regional Progress Report published by the SGC presents a framework for measuring sustainability based on twenty integrated, place-based quality-of-life regional indicators (http://dot.ca.gov/hq/tpp/offices/orip/Collaborative%20Planning/Files/CARegionalProgress_2-1-2011.pdf). Regional-scale issues such as air quality, housing affordability, vehicle miles traveled and electricity use form the basis for assessing the combined impact of regional outcomes on the state's sustainability. The Department is coordinating with SGC in order to more closely align the indicator analysis carried out in SGC's Regional Progress Reports with the Framework. In the first iteration of this coordination, water sustainability indicators may be adopted by the SGC regional reports as the method to measure this aspect of environmental, economic, and community well-being.

CDPH Healthy Community Indicators Project: The California Department of Public Health (CDPH) developed the Healthy Community Framework through an extended, grassroots community engagement process. This framework is the work product of a Health in All Policies Task Force. The Task Force is part of SGC and composed of high level representatives of 18 non-health state agencies and CDPH. CDPH has assembled a draft, preliminary, core list of indicators that links the framework's aspirational goals to evidence and data that are valid, frequently updated, and geographically relevant to potential local, regional, and state users. The preliminary set of indicators is being revised and vetted, and pilot implementation projects have begun with local health departments and other stakeholders on their use in their organizations. Over the next 2 years, CDPH will be making a considerable effort to research and develop a set of "Healthy Community Indicators" that includes much of the content of the social determinants of health.

USEPA California Footprint Sustainability Indicators Suite: California communities' future health and prosperity are fundamentally tied to sustainable water management. Communities are facing challenges like increasing population, aging infrastructure, groundwater depletion, degraded ecosystems, and climate change. To address these challenges, USEPA Region 9 has undertaken the California Footprint Sustainability Indicators Suite. As part of this effort, Region 9 is collaborating with DWR and the University of California, Davis (UCD) to develop the California Water Sustainability Indicators Framework, which as noted previously, involves the development of water sustainability indicators, water footprint, and a decision support tool. The project is supported by funding from the USEPA's Advance Monitoring Initiative and DWR. A water footprint and an ecological footprint at a state scale are being developed for the first time to pilot the decision support tool as a Global Earth Observation System of Systems project. The indicators suite also includes statewide indicators derived from satellite remote-sensing data -- a plant growth index and a total water and groundwater flux indicator. Collaborators include USEPA's Office of Research and Development, DWR, UCD, NASA's Jet Propulsion Laboratory, California State University - Monterey Bay, and US Geological Survey.

USEPA Healthy Watersheds Initiative: The Healthy Watersheds concept promoted by the USEPA is based on a holistic systems approach to watershed protection and conservation. While other USEPA programs focus on restoring impaired waters, the Healthy Watersheds Initiative augments the watershed approach with proactive, holistic aquatic ecosystem conservation and protection. The Healthy Watersheds Initiative includes both assessment and management approaches that encourage states, local governments, watershed organizations, and others to take a strategic, systems approach to conserve healthy components of watersheds, and, therefore, avoid additional water quality impairments in the future (http://water.epa.gov/polwaste/nps/watershed/index.cfm). The Science Advisory Board (SAB) has developed a "Framework for Assessing and Reporting on Ecological Condition" (U.S. EPA, 2002) (http://yosemite.epa.gov/sab/sabproduct.nsf/7700D7673673CE83852570CA0075458A/$File/epec02009.pdf). This framework was developed as an organizational tool for reporting on information about the health of ecosystems through an integrated assessment of essential ecological attributes: the landscape condition, biotic condition, chemical/physical parameters, and critical watershed functional attributes such as the natural disturbance regime and hydrology/geomorphology. The Healthy Watersheds approach is: 1) identifying healthy watersheds on a state-wide basis and healthy components of other watersheds; and 2) conserving healthy watersheds and protecting healthy components of other watersheds.

The Delta Plan: Delta Vision Task Force established in 2008 concluded that Delta problems could not be solved in isolation – they were inextricably linked to statewide water supply, habitat, and flood management programs – and that stronger governance and accountability were a must. In response, the Legislature, water agencies, and environmental groups throughout the state united in 2009 to pass a series of water-related measures that included the Delta Reform Act. The Delta Reform Act established coequal goals of a more reliable water supply for California and protecting, restoring, and enhancing the Delta ecosystem as overarching State policy. The Act also created the Delta Stewardship Council (DSC) with the authority and responsibility to develop a legally enforceable Delta Plan, and to ensure that actions by State and local agencies in the Delta are consistent with the Plan (http://deltacouncil.ca.gov/).

After more than 2 years of extensive effort, public outreach, and stakeholder input, the Final Staff Delta Plan was released in May 2012 (http://deltacouncil.ca.gov/sites/default/files/documents/files/DeltaPlan_05-14-2012.pdf). The Plan relies on a mix of legally enforceable policies and essential recommendations to prioritize actions and strategies for improved water management, ecosystem restoration, and levee maintenance. The Plan has formulated a set administrative, output, and outcome performance measures to monitor progress toward achieving the Coequal Goals. Existing monitoring efforts (such as the efforts of the Interagency Ecological Program, California Water Quality Monitoring Council, and California Statewide Groundwater Elevation Monitoring) will be utilized to inform progress toward achieving the performance measures in the Delta Plan.

California Healthy Streams Partnership: The major intent of the Healthy Streams Partnership (HSP) is to promote the improvement of water quality in California streams by informing and encouraging changes in present perspectives and resource management decision and actions. Thus, it could function as the bridge between assessed conditions and desired conditions of a given stream. Based on recommendations of HSP Work Group, the My Water Quality web portal was developed (http://www.CaWaterQuality.net). The My Water Quality website houses the widest collection of water quality and ecosystem health data about the state's lakes, rivers, streams, wetlands and ocean waters. The goal is to provide timely information in an easy-to-understand manner for the public, environmental organizations, and water quality professionals. The HSP is exploring models for developing indices that translate the various data types into a report card format that provides an assessment of overall stream condition.

Alliance for Water Stewardship: Alliance for Water Stewardship (AWS) was formed in 2008 because of the clear need for a coherent international framework for responding to freshwater challenges (http://www.allianceforwaterstewardship.org/). AWS model is designed around capturing and enabling access to knowledge and expertise on best practice on water stewardship. AWS is working with water authorities, companies, local communities and environmentalists to establish a voluntary program for water managers and users to accomplish the following: an International Standard developed through an equitable, transparent, science-based, multi-stakeholder process; third-party verification to determine whether these standards have been met; a global brand that allows managers, users and organizations to demonstrate their compliance with or support for water stewardship; and training to promote achievement of water stewardship. The first draft of the International Water Stewardship Standard was released in March 2012 (http://www.allianceforwaterstewardship.org/assets/documents/AWS_Standard_First_Draft_v_03_13_2012.pdf). While the AWS Standard is international in scope, its application will be based around successful local partnerships through which decision-making on watershed-level actions are developed by all those with a stake in water management. The AWS Standard defines a set of water stewardship steps, principles, criteria, and indicators for how water should be stewarded at a site and watershed level in a way that is environmentally, socially, and economically sustainable.

Sustainable water Resources Roundtable: Since 2002, the Sustainable Water Resources Roundtable (SWRR) has brought together State, federal, corporate, nonprofit, and academic sectors to advance understanding of the nation's water resources and to help develop tools for understanding and ensuring their sustainability (acwi.gov/swrr/index.html). SWRR developed a framework of water sustainability indicators in 2008 (http://acwi.gov/swrr/Rpt_Pubs/prelim_rpt/index.html). SWRR identified a set of four sustainability principles for water resource management – 1) the value and limits of water, 2) shared responsibility, 3) equitable access, and 4) stewardship. SWRR has developed a set of 14 key sustainability indicators under five major foci of water sustainability – 1) water availability, 2) water quality, 3) human uses and health, 4) environmental health, and 5) infrastructure and institutions (see Volume 4 Reference Guide, "Draft Compendium of Feb. 5, 2008 Sustainable Water Resources Roundtable, National Indicators Draft Framework).

Planning for an Uncertain Future

California is dynamic and ever changing. And over the next decades its moving forces--population growth, a variable and changing climate, and a desire to promote water use efficiency, regional self-sufficiency, better water quality, and environmental sustainability—will significantly change the management of the state's water resources. A changing climate means we can no longer rely on past records as a good indication of the frequency, duration, and severity of future floods and droughts. Many future uncertainties and risks now confront decision-makers, water and resource managers, and land use planners who need to consider a range of possible future conditions. To prepare for future challenges in managing its water resources California must make strategic investments in many available resources management strategies from Volume 3. This includes water conservation, water recycling, conjunctive management of surface water and groundwater storage, and desalination of brackish and sea water to name a few. Because each region has limits to financial resources to implement these strategies, each must carefully evaluate strategy costs, benefits, and tradeoffs in a thoughtful and collaborative way to choose cost effective and robust strategies.

Uncertainties Affecting Future Water Management

Since Update 2005, the California Water Plan has used the concept of multiple future scenarios to capture a broad range of uncertain factors that affect water management, but over which water managers have little control. Scenarios are used to test the robustness of strategies by evaluating how well strategies perform across a wide range of possible future conditions. Robust strategies are those that perform sufficiently well in meeting water management objectives across many scenarios. The Water Plan organizes scenarios around themes of population growth, land use patterns, and climate change. Growth scenarios characterize a range of uncertainty surrounding how cities and other land managers will accommodate future population growth through infill development or expansion into areas of existing open space and agriculture. Climate scenarios explore how future climate change might influence timing, distribution, and amount of precipitation, storm runoff and water requirements.

Growth Scenarios

Future water demand is affected by a number of growth and land use factors like population growth, planting decisions by farmers, and size and type of urban landscapes. Water Plan Update 2013 quantifies several factors that together provide a description of future growth and how growth could affect water demand for the urban, agricultural, and environmental sectors. Growth factors are varied between the scenarios to describe some of the uncertainty faced by water managers. For example, no one can predict future population growth, so the Water Plan uses three different, but plausible population growth estimates when determining future urban water demands. In addition, the Water Plan considers up three different alternative views of future development density. Population growth and development density will reflect how large the urban landscape will become in 2050 and is used by the Water Plan to quantify encroachment into agricultural lands by 2050. Table 5-5 identify the growth scenarios relative to current trends using information from the Department of Finance and Public Policy Institute of California.

PLACEHOLDER Table 5-5 Conceptual Growth Scenarios

[Any draft tables, figures, and boxes that accompany this text for the advisory committee draft are included at the end of the chapter.]

For Update 2013, DWR worked with researchers at the University of California, Davis to quantify how California might grow through 2050. The UPlan model (see http://ice.ucdavis.edu/project/uplan for information on the UPlan model) was used to estimate a year 2050 urban footprint under the scenarios of alternative population growth and development density listed in Table 5-6. UPlan applies Geographic Information System technology with rules describing where future growth might occur to quantify the land area devoted to urban uses. Locations for future growth follow local General Plan rules as well as attractors to growth like roads and distracters to growth like land use restrictions. Table 5-7 describes the amount of land devoted to urban use for 2006 and 2050 and the change in the urban footprint for California under each scenario. Table 5-6 describes how future urban growth could impact the land devoted to agriculture in 2050. Irrigated land area is the total agricultural footprint. Irrigated crop area is the cumulative area of agriculture considering that many parts of the state plant and harvest more than one crop per year, known as multi-crop area. Each of the scenarios shows a decline in irrigated acreage over existing conditions, but to varying degrees.

PLACEHOLDER Table 5-6 Growth Scenarios (urban) – Statewide values (DRAFT)

[Any draft tables, figures, and boxes that accompany this text for the advisory committee draft are included at the end of the chapter.]

PLACEHOLDER Table 5-7 Growth Scenarios (agriculture) – Statewide values (DRAFT)

[Any draft tables, figures, and boxes that accompany this text for the advisory committee draft are included at the end of the chapter.]

Climate Scenarios

A significant improvement to the Water Plan scenarios in Update 2013 is a quantitative look at the uncertainty surrounding future climate change when evaluating the performance of new resource management strategies. After consultation with its Climate Change Technical Advisory Group, DWR chose to include as many as 18 alternative climate scenarios in the evaluation of future strategies. These include 12 climate scenarios identified by the Governor's Climate Action Team (CAT), 5 climate scenarios developed by the Bureau of Reclamation for the Central Valley Project Integrated Resource Plan (2012, under development), and a scenario representing a repeat of historical climate. Each of the climate scenarios has separate estimates of future precipitation and temperature. Collectively these estimates provide planners with a range of precipitation and temperature that might be experienced in the future and are used with other factors to estimate future water demands. Refer to the article in Volume 4 Reference Guide, "Overview of Climate-change Scenarios being Analyzed" for additional information on the CAT climate scenarios.

Figures 5-5, 5-6, 5-7, and 5-8 show the variation in 30 year running average annual precipitation for locations in the Central Valley and Sierra Nevada foothill regions for the 1915-2003 historical period and U.S. Bureau of Reclamation scenarios of future climate, and 2011-2099 for the 12 CAT scenarios of future climate. The variation in the 30 year running average precipitation is represented as a box plot (also known as a box-and-whisker diagram or plot), which is a convenient way of graphically summarizing groups of numerical data using five numbers (the smallest observation, lower quartile (Q1), median (Q2), upper quartile (Q3), and largest observation). For example, for the historical period, the box plot for Red Bluff shows a minimum value of about 20 inches in the driest 30 year period and a maximum value of slightly over 23 inches in the wettest 30 year period. The precipitation values used to generate the box plots are from a specific point in each location.

PLACEHOLDER Figure 5-5 Variation in 30 Year Running Average Precipitation for Red Bluff for Historical Record (1915-2003) and Alternative Scenarios of Future Simulated Climate (2011-2099)

[Any draft tables, figures, and boxes that accompany this text for the advisory committee draft are included at the end of the chapter.]

PLACEHOLDER Figure 5-6 Variation in 30 Year Running Average Precipitation for Oroville for Historical Record (1915-2003) and Alternative Scenarios of Future Simulated Climate (2011-2099)

[Any draft tables, figures, and boxes that accompany this text for the advisory committee draft are included at the end of the chapter.]

PLACEHOLDER Figure 5-7 Variation in 30 Year Running Average Precipitation for Fresno for Historical Record (1915-2003) and Alternative Scenarios of Future Simulated Climate (2011-2099)

[Any draft tables, figures, and boxes that accompany this text for the advisory committee draft are included at the end of the chapter.]

PLACEHOLDER Figure 5-8 Variation in 30 year Running Average Precipitation for Millerton for Historical Record (1915-2003) and Alternative Scenarios of Future Simulated Climate (2011-2099)

[Any draft tables, figures, and boxes that accompany this text for the advisory committee draft are included at the end of the chapter.]

Figure 5-9 shows the trend in the change in average annual temperature for the Sacramento Valley floor for each climate sequence compared against the 1951–2005 historical average. A distinct upward trend in temperature change is shown in each climate scenario. However, there is considerable year-to-year fluctuation and different expectations for the long-term magnitude in temperature change. While the absolute change in temperature varies from region to region, the relative change in average annual temperature follows a similar pattern in all regions to that shown for the Sacramento River Hydrologic Region in Figure 5-9.

PLACEHOLDER Figure 5-9 Change in Average Annual Temperature for Sacramento Valley Floor from Historical 1951-2005 Average for Historical Period and 12 Scenarios of Future Climate Years 2006-2100

[Any draft tables, figures, and boxes that accompany this text for the advisory committee draft are included at the end of the chapter.

Future Environmental Requirements

The Water Plan uses currently unmet environmental objectives as a surrogate to estimate new requirements that may be enacted in the future to protect the environment or new ecosystem restoration actions implemented for example, under an integrated regional water management plan. These unmet objectives are instream flow needs or additional deliveries to managed wetlands that have been identified by regulatory agencies or pending court decisions, but are not yet required by law. For Update 2013 the Water Plan has identified the following unmet objectives.

- American (Nimbus) Department of Fish and Game Values
- Stanislaus (Goodwin)
- Ecosystem Restoration Program #1, Delta Flow Objective
- Ecosystem Restoration Program #2, Delta Flow Objective
- Ecosystem Restoration Program #4, Freeport
- Trinity below Lewiston
- Ecosystem Restoration Program #3 San Joaquin River at Vernalis
- San Joaquin River below Friant
- Level 4 Water Deliveries to Wildlife Refuges

These are only some of the unmet objectives and do not include all environmental objectives in the state. In particular, they do not include additional water to protect species in the Delta resulting from the December 2008 Delta Smelt Biological Opinion issued by the U.S. Fish and Wildlife Service or to protect salmon and several other species resulting from the June 2009 biological opinion by the National Marine Fisheries Service.

Statewide and Hydrologic Region 2050 Water Demands

[Results under development - This section will include statewide results of future change in water demand considering uncertainties surrounding future population growth, land use decisions, and climate change]

Evaluating Resource Management Strategies for Three Hydrologic Regions

Throughout development of Update 2013 DWR has worked with the Statewide Water Analysis Network (SWAN serves as the technical advisory committee for the Water Plan) to develop methods to regionally quantify and evaluate the costs, benefits, and tradeoffs of different resource management strategies through the application of the Water Evaluation And Planning (WEAP) modeling platform. The Water Plan is testing the evaluation methods by focusing on the three hydrologic regions capturing the Central Valley: The Sacramento River, San Joaquin River, and Tulare Lake Hydrologic Regions (see Figure 5-10). The proposed analysis for these three regions has been documented in the Plan of Study for Update 2013 available at:http://www.waterplan.water.ca.gov/docs/cwpu2013/ae/future_scenarios-plan_of-study.pdf

PLACEHOLDER Figure 5-10 California's Hydrologic Regions Highlighting Three Central Valley Regions Used in Test Case

[Any draft tables, figures, and boxes that accompany this text for the advisory committee draft are included at the end of the chapter.

WEAP is used to represent both the physical water management system and existing and potential resource management strategies. The physical water management system is represented by estimates of current and future precipitation, runoff to streams and rivers, flows into surface reservoirs, and many other components represented conceptually in Figure 5-11.

PLACEHOLDER Figure 5-11 Conceptual Model of Water Management System

[Any draft tables, figures, and boxes that accompany this text for the advisory committee draft are included at the end of the chapter.]

Table 5-8 summarizes the Update 2013 Plan of Study components in terms of the key uncertain scenario factors, performance metrics, resource management strategies and response packages, and relationships. This table, also called an XLRM matrix (Lempert et al., 2003), summarizes these elements and is designed to clearly distinguish among the uncertain factors (X) that are used to develop the uncertain scenarios; the water management strategies (L) that comprise the response packages; the performance metrics (M) that are used to evaluate and compare response packages; and the relationships (R) among these elements that are reflected in the planning models. DWR used this matrix when developing the scoping of the analysis and communicating it to stakeholders. See the Plan of Study for a detailed description of each factor shown in Table 5-8.

PLACEHOLDER Table 5-8 Update 2013 Plan of Study Components (DRAFT)

[Any draft tables, figures, and boxes that accompany this text for the advisory committee draft are included at the end of the chapter.]

Management Response Packages

As described in the Plan of Study, Update 2013 evaluates several management response packages, each comprised of a mix of resource management strategies that are implemented at specific levels and locations. The focus of this analysis will be for the Sacramento River, San Joaquin River, and Tulare Lake Hydrologic Regions, and will include strategies that are regionally significant. For example, a response package could include improvements in urban water use efficiency that is specified to increase to 20 percent savings by 2020, additional groundwater storage, or increasing water for ecosystem restoration.

These response packages will not represent a definitive set of alternatives, rather illustrate different levels of strategy diversification that could be taken to address water management challenges. Each response package emphasizes one or more of the strategy categories. Table 5-9 lists a preliminary proposal for the relative levels of strategy emphasis by category for six response packages. The corresponding implementation specifics for each strategy are under development. Additional response packages may be developed that are specifically tailored to address the vulnerabilities of currently planned management.

PLACEHOLDER Table 5-9 Resource Management Strategies Used in Plan of Study (DRAFT)

[Any draft tables, figures, and boxes that accompany this text for the advisory committee draft are included at the end of the chapter.

Water Management Vulnerabilities

[Results under development – This section will describe some of the key water management vulnerabilities identified as part of the analysis to regionally quantify and evaluate the costs, benefits, and tradeoffs of different resource management strategies identified in the Plan of Study described in the previous section

Limitations of Future Water Management Analysis for Update 2013

The analysis of resource management strategies developed for Update 2013 can allow comprehensive analysis of strategy performance when conducted at sufficient detail. However, all technical endeavors are subject to the limits of the particular technology being used and the financial resources available. Below are some of the important limitations the Water Plan team has identified for the analysis used for Update 2013.

- For Update 2013, DWR tested the more comprehensive analysis described in this section for the Sacramento River, San Joaquin River, and Tulare Lake Hydrologic Regions. The analysis for the remaining 7 hydrologic regions in California was coarser and focused on quantifying future water demands under alternative future scenarios similar to the analysis performed for Update 2009.
- Many of the resource management strategies identified in Volume 3 can be represented in the Update 2013 application of WEAP, particularly those related to the water management

objectives to reduce water demand, improve operational efficiency and transfers, and increase water supply. However, the analysis for Update 2013 had limited to no ability to quantify strategies that improve flood management, improve water quality, and practice resource stewardship. These will be considered as part of future enhancements to the analytical framework.

- The analysis for Update 2013 quantified some of the resource management strategy benefits for providing a supply benefit, improving drought preparedness, environmental benefits, operational flexibility and efficiency, and reducing groundwater overdraft. There was limited to no ability to quantify benefits for improving water quality, reducing flood impacts, energy benefits, and recreational opportunities; however, these may be described qualitatively. Quantifying these other benefits will be considered as part of future enhancements to the analytical framework.
- The conceptual water management system in Figure 5-11 captures many of the hydrologic and water management components that are represented in the analytical framework for Update 2013. The analysis to support the Water Plan is designed to represent the water management system at sufficient detail to reflect important planning conditions, but not for detailed water project operations or to capture all detailed flows through the system. As a result, many system features, such as groundwater basins, are simplified to capture the broad regional behavior of groundwater recharge, groundwater storage, and hydrologic connection to rivers and lakes. Significant refinement in the analysis will be needed to support decisions by individual water districts.

Summary

Integrated water management is the basis for California's water planning. This umbrella approach recommends that California and its regions consider how a portfolio of resource management strategies described in Volume 3 might meet multiple water management objectives in light of many risks and uncertainties and ensure sustainable use of water resources. DWR and other entities are conducting various risk assessments so risks can be better balanced with the rewards for improved management. And Update 2013 introduced a water sustainability indicators framework to ascertain how the objectives of the Water Plan, associated resource management strategies, and recommended actions would lead to sustainable water use and supply for the State and its ten hydrologic regions.

Update 2013 evaluated how statewide and regional water demands might change by 2050 in response to uncertainties surrounding future population growth, land use changes, the effect future climate change, and other factors. These future uncertainties will play out quite differently across the regions of California, so each region will need to choose and implement a portfolio of resource management strategies that satisfy regional water management goals and objectives. Update 2013 also conducted a more comprehensive vulnerability analysis for the Sacramento River, San Joaquin River, and Tulare Lake regions to test longer term analytical enhancements for the Water Plan. This analysis tested different response packages, or combinations of resource management strategies, under many future uncertainties. These response packages help decision-makers, water managers, and planners develop and evaluate integrated water management plans that invest in actions with more sustainable outcomes.

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Table 5-1 Definitions of Terms Used in the California Water Sustainability Indicators Framework

Term	Definition
Goal	Goal, as used in the Framework, is a broad statement of intent about where a community or society would like to end up
Objective	Objectives are more detailed, specific, and measurable aspects of a broader goal.
System	A system, as the term is used here, is a set of interacting parts, where both the components and the relationships among them are intrinsically linked.
Theme/domain	Themes and domains are types of category (i.e., collection of like attributes) and are terms of art referring to large parts of natural or social systems (e.g., landscape condition).
Target	Targets/reference conditions/desired future conditions refer to the state where we want the indicators to be to reach water sustainability.

Source: California Department of Water Resources 2012.

Table 5-2 Definitions of Terms Used in the California Water Sustainability Indicators Framework

Term	Definition
Goal	Goal, as used in the Framework, is a broad statement of intent about where a community or society would like to end up.
Objective	Objectives are more detailed, specific, and measurable aspects of a broader goal.
System	A system, as the term is used here, is a set of interacting parts, where both the components and the relationships among them are intrinsically linked.
Theme/domain	Themes and domains are types of category (i.e., collection of like attributes) and are terms of art referring to large parts of natural or social systems (e.g., landscape condition).
Target	Targets/reference conditions/desired future conditions refer to the state where we want the indicators to be to reach water sustainability.

Source: California Department of Water Resources 2012.

Table 5-3 Sustainability Goals and Objectives for California Water

Sustainability Goals and Objectives	Relationship to Water Plan 2009
Goal 1: Manage and make decisions about water in a way that integrates water availability, environmental conditions, and community well-being for future generations.	Reflects overall goal of sustainability
Goal 2. Improve water supply reliability to meet human needs, reduce energy demand, and restore and maintain aquatic ecosystems and processes. *Objectives: Improve water use efficiency; Increase water recycling; Increase water conservation*	Water Plan Objective 2, 9; RMS Reduce demand
Goal 3. Contribute to social and ecological beneficial uses and reduce impacts associated with inter-basin water transfers and to the Delta. *Objectives: Improve regional water movement operations and efficiency; Investigate new water technologies; Protect ecosystem services and benefits provided by intact and naturally-functioning Delta*.	Water Plan Objective 1, 2, 7, 11, RMS Operational efficiency
Goal 4. Increase quantity, quality, and reliability of drinking water, irrigation water, and in-stream flows *Objectives: Increase conjunctive management of new and recycled water from multiple sources*.	Water Plan Objective 3, 12, 13; RMS Increase water supply
Goal 5. Safeguard human and environmental health and secure California water supplies *Objectives: Protect and restore surface water and groundwater quality; Protect the natural systems that maintain these services*.	Water Plan Objective 4; RMS on water quality; chapter 4 discussion of water quality sustainability indicators
Goal 6. Protect and enhance environmental conditions by improving watershed, floodplain, and aquatic condition and processes. *Objectives: Practice,*	Water Plan Objective 5, 12, 13; RMS Natural Resources
Goal 7. Integrate flood risk management with other water and land management and restoration activities. *Objectives: Improve land-use/cover to reduce flood risk; Improve floodplain-channel connections*.	Water Plan Objective 1, 6, 12, 13; RMS Improve flood
Goal 8. Support decision-making, especially in light of uncertainties, that support integrated regional water management and flood and water resources management systems. *Objectives: Improve and expand monitoring, data management, and analysis*.	Water Plan Objective 10; various RMSs; CWP Vol. 1 Chapter 6 Integrated Data and Analysis

Source: California Department of Water Resources 2012.

Table 5-4 Water Footprint and Related Terms

Term	Definition
Water footprint	The total volume of water consumed and needed to assimilate pollutants in the production of goods and services used by an individual or jurisdiction (e.g., state, country).
Internal water footprint (of consumption)	The total volume of water consumed and needed to assimilate pollutants in the production of goods and services used by a given jurisdiction (e.g., state, country) that originates from within that jurisdiction
External water footprint (of consumption)	The total volume of water consumed and needed to assimilate pollutants in the production of goods and services by a given jurisdiction (e.g., state, country) that originates from outside that jurisdiction
Virtual water	The volume of water consumed directly (operations) and indirectly (supply chain) to produce a good or service.
Green water	The volume of precipitation and precipitation stored in the soil that is directly consumed in an activity, such as in the growing of crops.
Blue water	The volume of surface and groundwater that is applied and consumed in an activity.
Grey water	The volume of water necessary to assimilate pollutants back into water bodies at levels that meeting governing standards, regardless of whether those standards are actually met

Source: California Department of Water Resources 2012.

Table 5-5 Conceptual Growth Scenarios

Scenario	Population Growth	Development Density
1	Lower than Current Trends	Higher than Current Trends
2	Lower than Current Trend	Current Trends
3	Lower than Current Trends)	Lower than Current Trends
4	Current Trends	Higher than Current Trends
5	Current Trends	Current Trends
6	Current Trends	Lower than Current Trends
7	Higher than Current Trends	Higher than Current Trends
8	Higher than Current Trends	Current Trends
9	Higher than Current Trends	Lower than Current Trends

Source: California Department of Water Resources 2012.

Table 5-6 Growth Scenarios (urban) – Statewide values (DRAFT)

2006 Population was 36.1 million

2006 Urban Footprint was 5.2 million acres

Scenario	2050 Population (millions)	Population Change (millions) 2006 to 2050	Development Density	2050 Urban Footprint (million acres)	Urban Footprint Increase (million acres) 2006 t0 2050
1	43.9[a]	7.8	High	5.6	0.3
2	43.9	7.8	Current Trends	6.2	1.0
3	43.9	7.8	Low	6.5	1.2
4	51.0[b]	14.9	High	6.3	1.1
5	51.0	14.9	Current Trends	6.7	1.5
6	51.0	14.9	Low	7.1	1.9
7	69.4[c]	33.3	High	6.8	1.6
8	69.4	33.3	Current Trends	7.6	2.4
9	69.4	33.3	Low	8.3	3.1

Source: California Department of Water Resources 2012.

a Values modified by Department of Water Resources from the Public Policy Institute of California

b Values from Department of Finance

c Values modified by Department of Water Resources from the Public Policy Institute of California

Table 5-7 Growth Scenarios (agriculture) - Statewide values (DRAFT)

2006 Irrigated land area was estimated by DWR to be 8.7 million acres

2006 Irrigated crop area was estimated by DWR to be 9.3 million acres

2006 Multiple crop area was estimated by DWR to be 0.65 million acres

Scenario	2050 Irrigated Land Area (million acres)	2050 Irrigated Crop Area (million acres)	2050 Multiple Crop Area (million acres)	Reduction in Irrigated Crop Area (million acres) 2006 to 2050
1	8.6	9.2	0.65	0.1
2	8.4	9.0	0.63	0.3
3	8.3	8.9	0.63	0.4
4	8.4	9.0	0.63	0.3
5	8.2	8.9	0.62	0.4
6	8.1	8.7	0.61	0.6
7	8.2	8.9	0.62	0.4
8	8.0	8.6	0.60	0.7
9	7.8	8.4	0.58	0.9

Source: California Department of Water Resources 2012.

Table 5-8 Update 2013 Plan of Study Components (DRAFT)

Uncertain factors (X)	Resource management strategies (L)
• Demographics • Urban and agricultural footprint • Climate conditions • Costs of resource management strategies	Currently planned management Additional water management strategies: • Urban water use efficiency • Agricultural water use efficiency • Recycled municipal water • Conjunctive management and groundwater storage • Surface storage • System reoperation • Meet new instream flow objectives • Groundwater overdraft recovery
Relationships (R)	**Performance metrics (M)**
• Water Evaluation And Planning system (WEAP) Central Valley Model • Upland urban growth model • Statewide Agricultural Production model (SWAP) • Demographic analysis • Costs and economic impact tools	• Urban supply reliability • Agricultural supply reliability • Instream flow reliability • Groundwater levels • Sacramento-San Joaquin River Delta exports (Central Valley Project and State Water Project) • Cost of implementing response packages • Economic impacts of unmet water demand

Source: California Department of Water Resources 2012.

Table 5-9 Resource Management Strategies Used in Plan of Study (DRAFT)

Response Package	Resource Management Strategy Category			
	Water use efficiency	**Reuse and conjunctive management**	**Additional environmental flows and groundwater recovery**	**New Surface storage**
Currently planned management	currently planned	currently planned	currently planned	none
Diversification Level 1	moderate	moderate	currently planned	none
Diversification Level 2	aggressive	moderate	moderate	none
Diversification Level 3	aggressive	aggressive	moderate	one facility
Diversification Level 4	aggressive	aggressive	aggressive	two facilities

Source: Department of Water Resources 2012

Figure 5-1 Understanding Flood Risks

Understanding Flood Risks

Flood risk reflects both the probability of flooding and the consequences that would result from flooding. Flood risk can be calculated as:

(Probability) x (Consequence) = Flood Risk

For example, if an agricultural area has an annual 1 in 50 chance of flooding causing $10 million worth of damage, the annual flood risk for this area would be:

1/50 x $10 million = $200,000 per year

If levees are improved so that the area has an annual 1 in 100 chance of flooding, the risk is cut in half:

1/100 x $10 million = $100,000 per year

However, if the area begins to be urbanized and new homes, businesses, and infrastructure are added, the damages or consequences resulting from flooding become much greater. If the consequences of flooding rise from $10 million to $100 million, the flood risk is greatly increased:

1/100 x $100 million = $1,000,000 per year

So, even when the level of flood protection goes up, the risk may be higher if more people and infrastructure are located in the floodplain. For heavily urbanized areas in deep floodplains, the annual risk is commonly in the billions of dollars.

As we saw in New Orleans after Hurricane Katrina, there is also a huge potential for loss of life and countless personal tragedies when we urbanize in deep floodplains. Such losses are difficult to measure in economic terms, but cannot be overlooked. California is working to reduce flood risk in existing urbanized areas and avoid putting people at risk in areas that do not have adequate flood protection.

Figure 5-2 Probability of a Number of Simultaneous Levee Failures from a Seismic Event During a 25-year Exposure Period

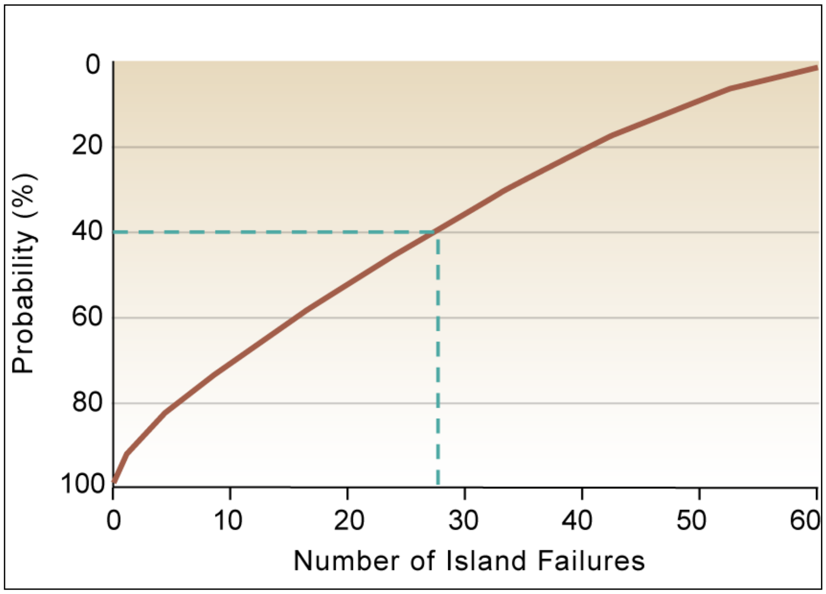


Figure 5-3 Delivered Supply, Surplus, and Shortages for the Hotter and Drier Miss Goals Scenario under the 2005 IEUA Urban Water Management Plan

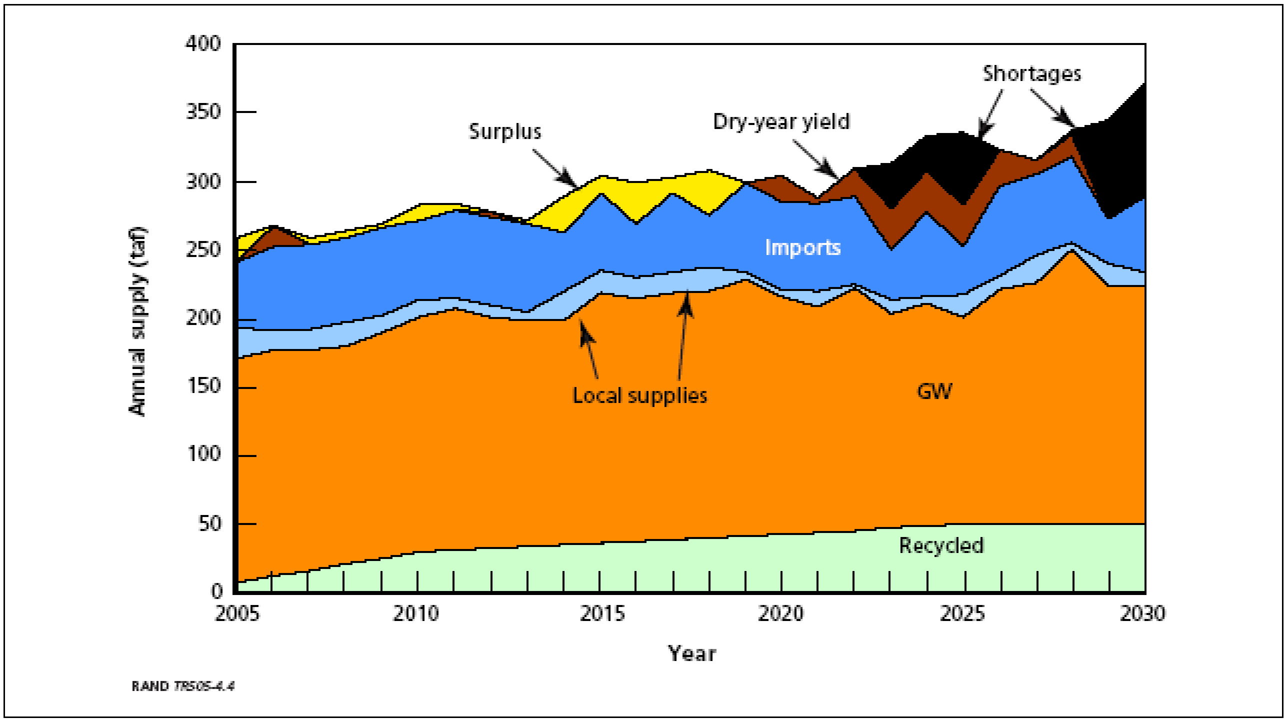


Figure 5-4 The California Water Sustainability Indicators Framework

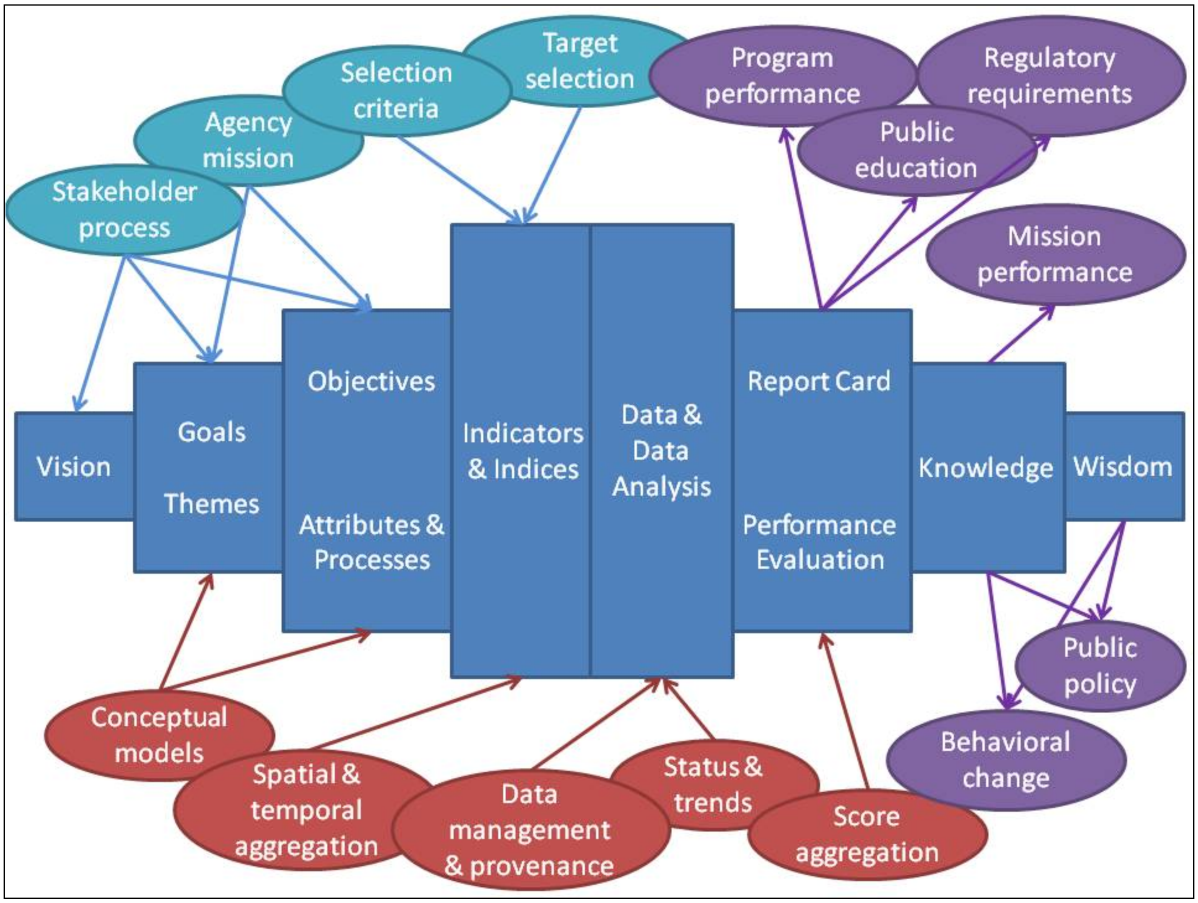


Figure 5-5 Variation in 30 year Running Average Precipitation for Historical Record (1915-2003) and Alternative Scenarios of Future Simulated Climate (2011-2099) for Red Bluff

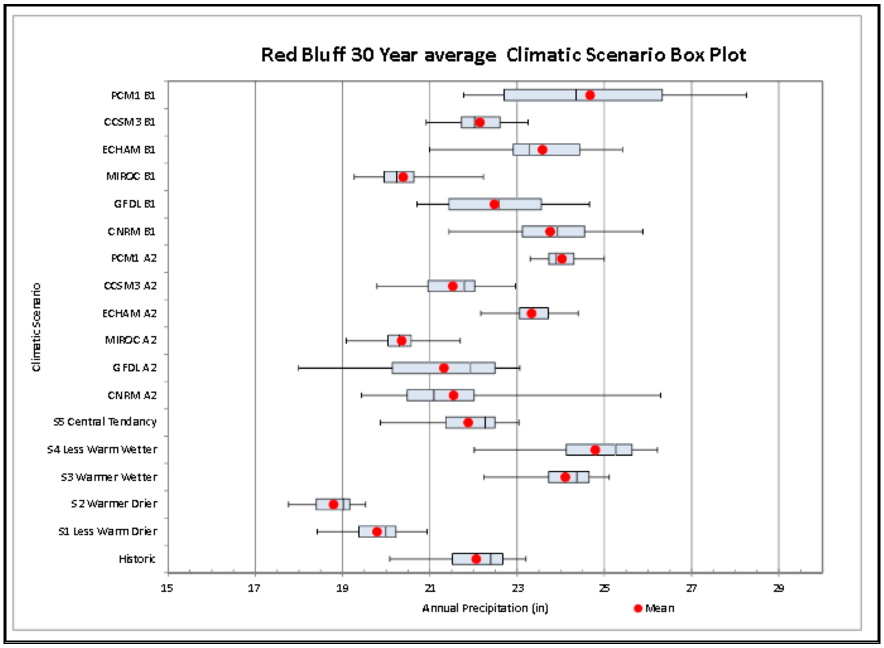


Figure 5-6 Variation in 30 year Running Average Precipitation for Historical Record (1915-2003) and Alternative Scenarios of Future Simulated Climate (2011-2099) for Oroville

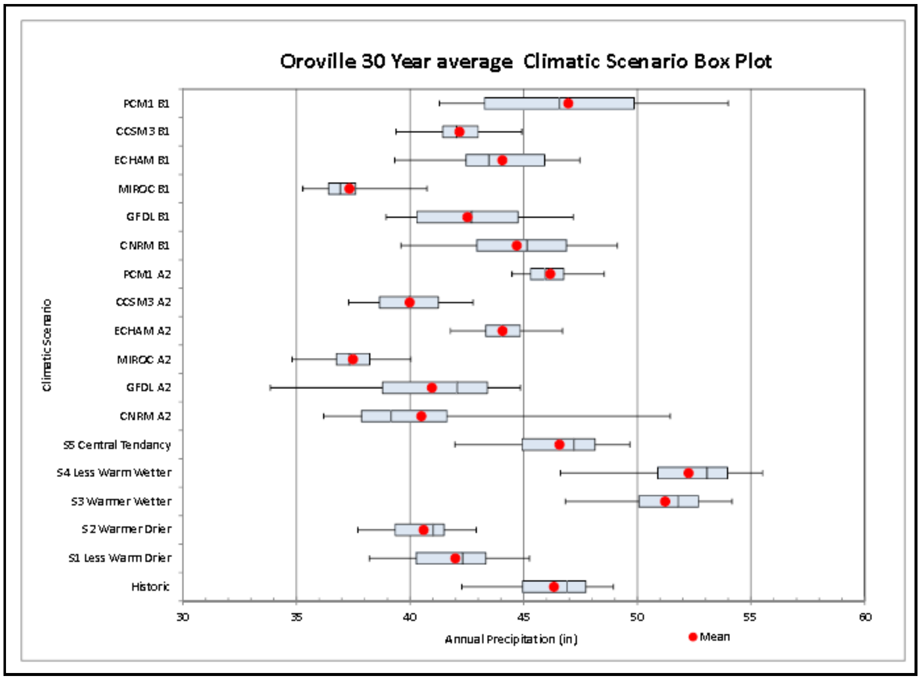


Figure 5-7 Variation in 30 year Running Average Precipitation for Fresno for Historical Record (1915-2003) and Alternative Scenarios of Future Simulated Climate (2011-2099)

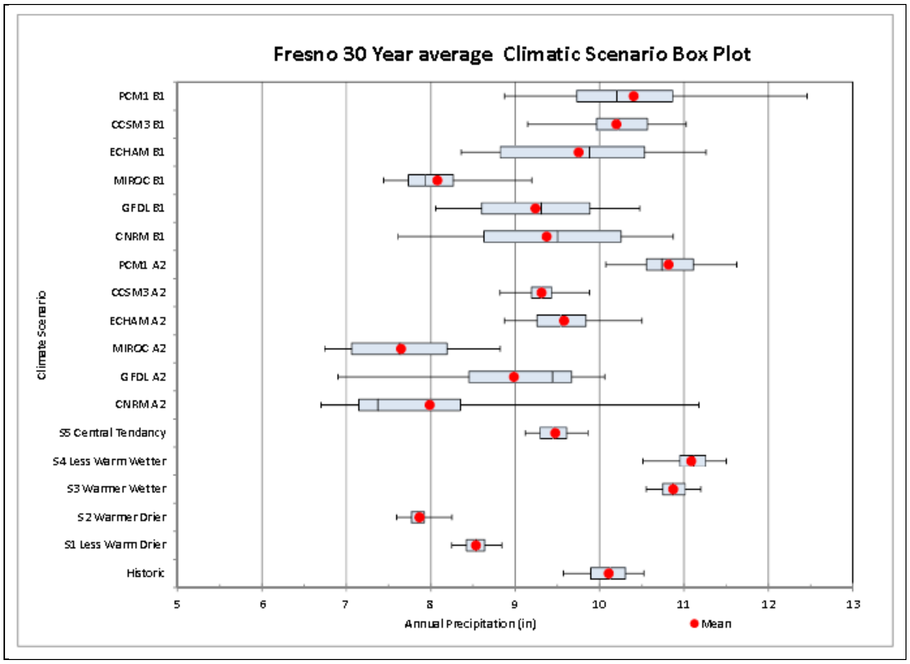


Figure 5-8 Variation in 30 year Running Average Precipitation for Millerton for Historical Record (1915-2003) and Alternative Scenarios of Future Simulated Climate (2011-2099)

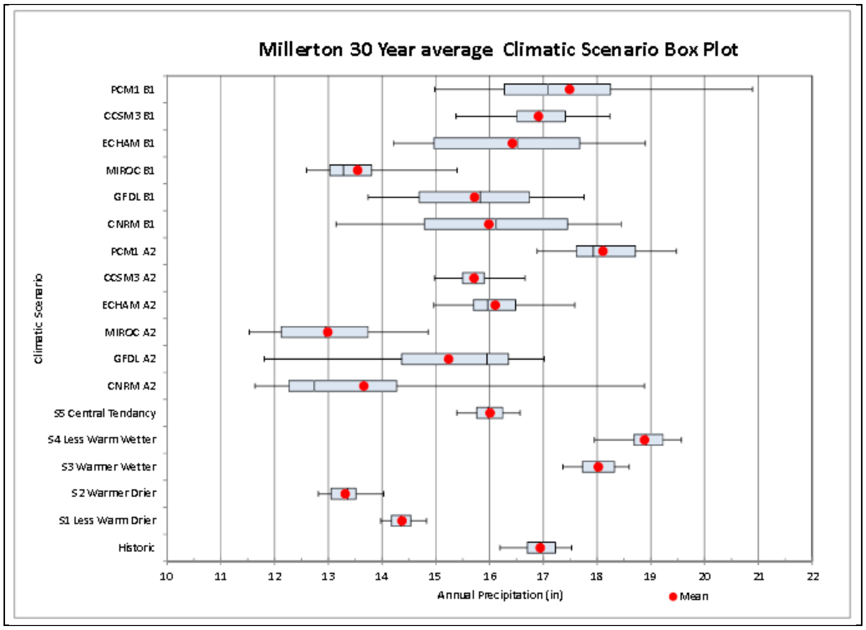
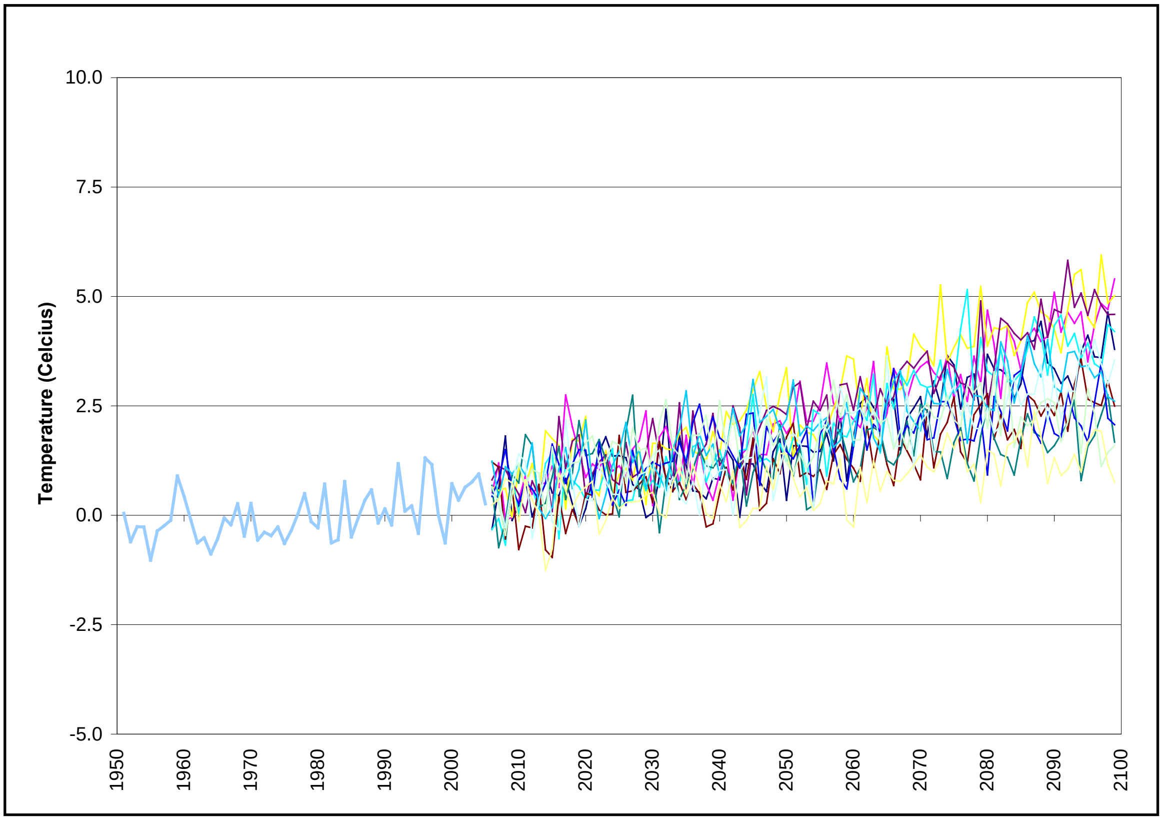


Figure 5-9 Change in Average Annual Temperature for Sacramento Valley floor from Historical 1951-2005 Average for Historical Period and 12 Scenarios of Future Climate Years 2006-2100



NOTE: In this figure, historical period shows actual demand (blue line). Each colored line represents 1 of 12 climate scenarios.

Figure 5-10 California's Hydrologic Regions Highlighting Three Central Valley Regions Used in Test Case

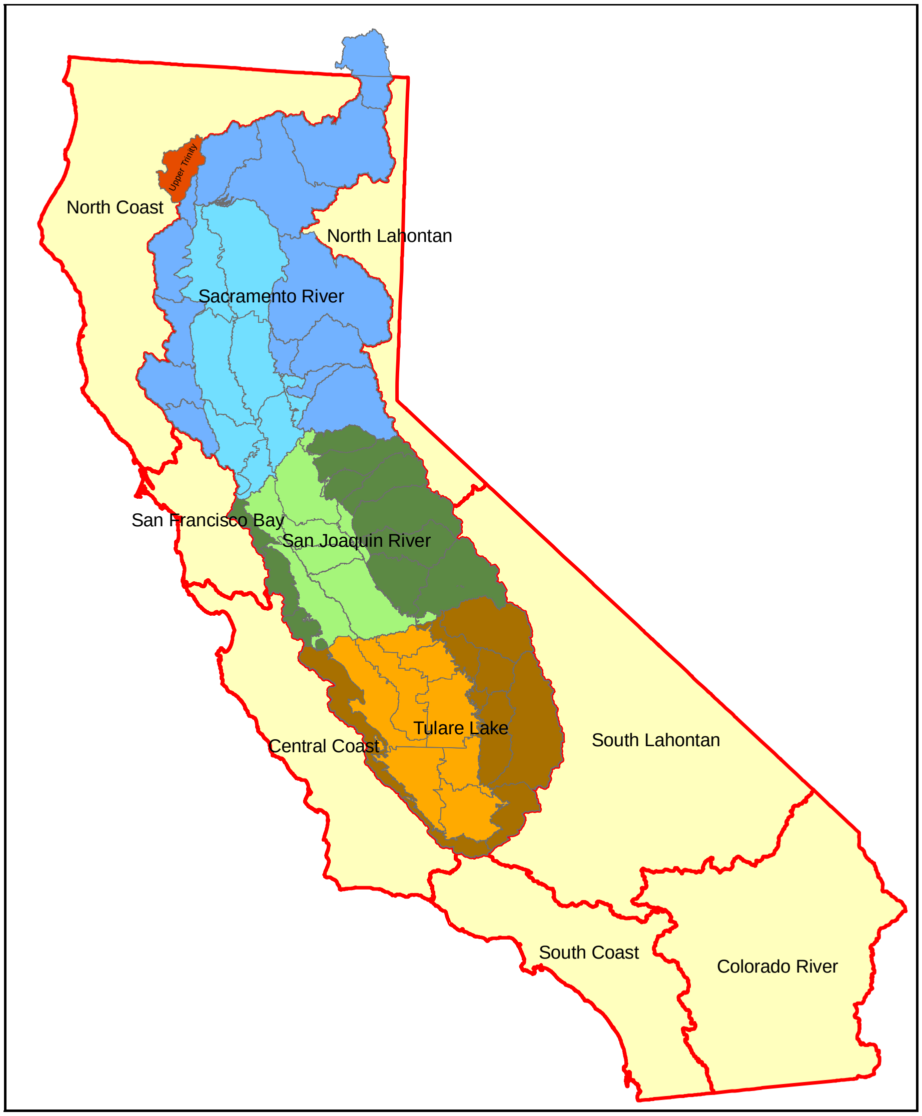
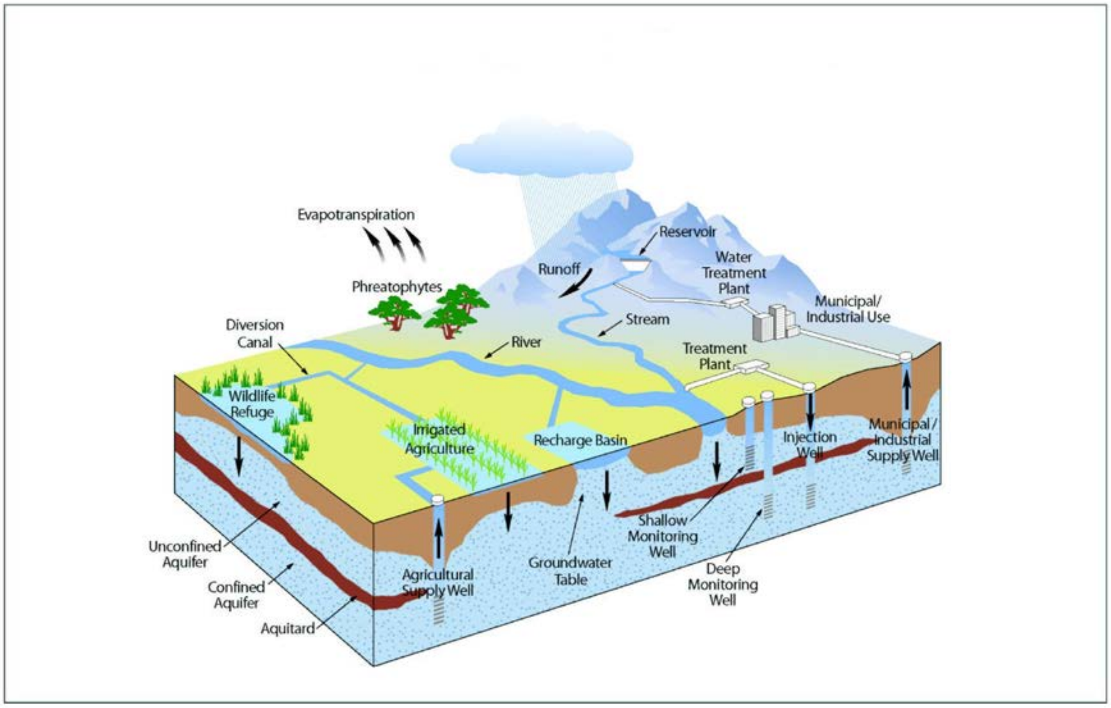


Figure 5-11 Conceptual Water Management System



Box 5-4 Many Objective Robust Decision Making

By Joseph R. Kasprzyk, Shanthi Nataraj, Patrick M. Reed, Pennsylvania State University, Dept. of Civil and Environmental Engineering and Robert J. Lempert, RAND Corporation

Water resources planning has traditionally used historical data within benefit-maximizing frameworks for system design. The validity of this approach is threatened by environmental change and population growth, which create *deep uncertainties* that modify the distributions of data that characterize the system. Furthermore, solutions from the traditional benefit-maximizing approaches may prove inferior when multiple, complex objectives are introduced (e.g., maximizing reliable performance or environmental quality). Many Objective Robust Decision Making (MORDM) was developed to solve such multiobjective problems under deep uncertainty, by combining many-objective evolutionary algorithm (MOEA) optimization, robust decision making (RDM) and interactive visual analytics. MORDM was recently demonstrated using a risk-based water supply portfolio planning problem in the Lower Rio Grande Valley of Texas.

PLACEHOLDER Figure A The MORDM Framework

[This draft figure follows the text of this box]

The framework, presented in Figure A, begins with a **Problem Formulation** (XLRM): uncertainties beyond the decision maker's control (X); decision levers that can modify the system (L); measures (M) to quantify performance; and a relationship (R), generally a simulation model that maps the decision maker's actions to performance outcomes. The second step, **Generating Alternatives,** uses a MOEA to generate multiple planning alternatives or strategies, using a baseline state of the world (SOW) to calculate values for multiple output measures. MORDM uses an *a posteriori* approach to decision support, with no weight or preferences defined in the beginning of the analysis. Presenting the full range of output measure values allows users to often discover surprising relationships between alternative solutions. For example, the spatial coordinates in Figure B section a show a contrast between high cost alternatives (solution 2) and solutions with higher numbers of leases that exhibit lower costs (solution 1). After the tradeoffs are generated, **Uncertainty Analysis** globally samples deeply uncertain exogenous factors and evaluates the performance of each alternative in multiple SOWs. Color in Figure B section a shows each solution's percent deviation in a Critical Reliability measure compared to the measure in the baseline SOW. Solution 4 has very low deviation compared to Solutions 1-3, indicating robust performance across many SOW. **Scenario Discovery and Tradeoff Analysis** then uses statistical cluster analysis to provide simple, easy-to-understand descriptions of the combinations of deeply uncertain factors that cause the chosen robust solutions to perform poorly. Figure B section b shows an example in which high losses, low inflows, and high demands could cause performance vulnerabilities for the solution. The results motivate monitoring of system states and further adaptive planning to ameliorate these vulnerabilities. In summary, MORDM can help decision makers formulate problems, generate promising management alternatives, and evaluate the robustness of those alternatives in an uncertain future.

PLACEHOLDER Figure B Example MORDM Results

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Figure A The MORDM Framework

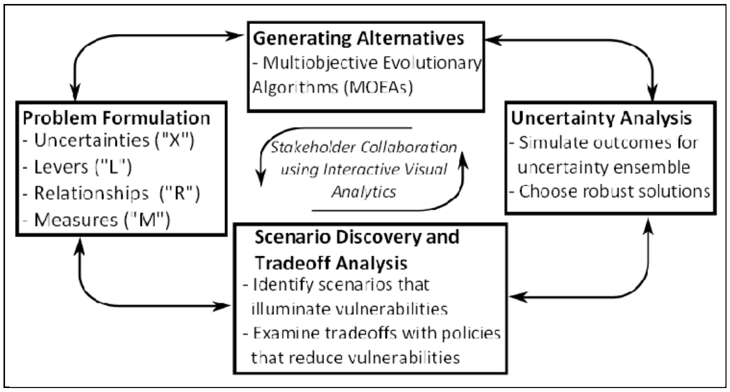

Figure B Example MORDM Results

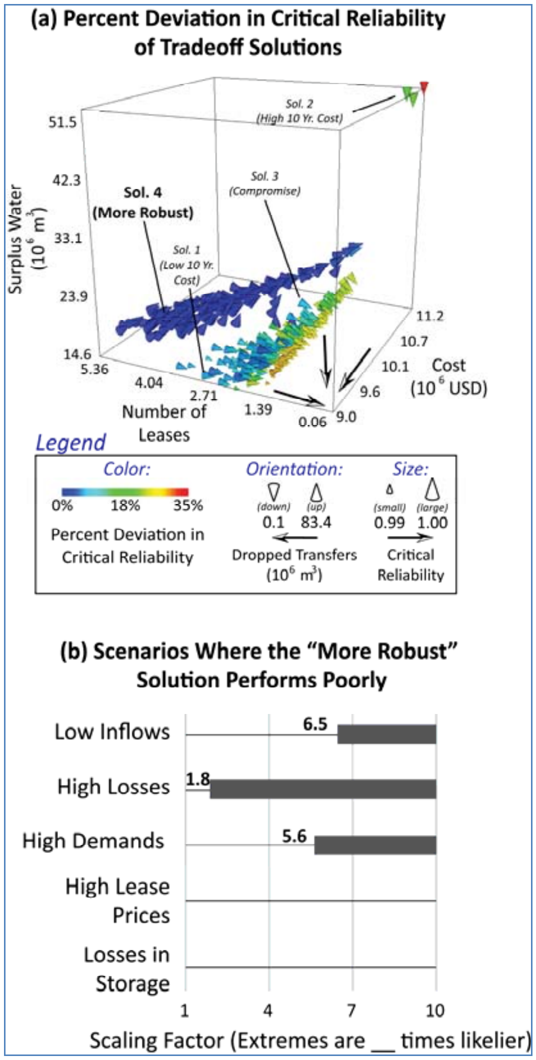

Figure B Example MORDM results. Section a uses coordinates, orientation, and size to show measure values in the baseline SOW. Color is an indicator of the change in critical reliability under the uncertainty ensemble. Section b uses Scenario Discovery to discover ranges of uncertainty in which the solution performs poorly on a suite of reliability measures.

Box 5-5 Sustainability Definitions

There are many definitions of sustainability in the literature. Brundtland Commission (1983) provides a general definition of sustainability as

> "A system that is sustainable, should meet today's needs without compromising the ability of future generations to meet their own needs"

The US Environmental Protection Agency (USEPA) defines sustainability as

> "The satisfaction of basic economic, social, and security needs now and in the future without undermining the natural resource base and environmental quality on which life depends"

The state of Minnesota adopted the following definition of sustainable water use as part of their Water Sustainability Framework,

> "That which does not harm ecosystems, degrades water quality, or compromise the ability of future generations to meet their own needs"